*Indian J. Phys.* **73B** (3), 537-543 (1999)

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**IJP B**
— an international journal

# Radiation of 8 × 8 element planar array of circular patch microstrip antenna

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*Received 2 September 1998, accepted 16 December 1998*

**Abstract** : An analysis of a new type of 8 × 8 element planar array of circular patch microstrip antenna (CPMA) is presented at 10GHz. The array factor and far-zone field expressions of the array geometry are obtained by using a pattern multiplication approach and vector wave function technique The total field patterns and other important antenna parameters like half power beam width (HPBW), direction of maximum radiation, first null beam width (FNBW), total shift of major and first minor lobe, side lobe level (SLL), radiation conductance and directive gain are computed and plotted for two different values of progressive phase excitation difference between the elements It is observed that the radiation properties of the array geometry are modified considerably by changing the phase excitation difference between the elements.

**Keywords** Microstrip planar array, radiation properties

**PACS No.** : 84 40.Ba

Because of many unique and attractive properties like light weight, low cost, compatibility with integrated circuits and better aerodynamic properties, microstrip printed circuit technology has attracted the attention of many investigators [1-3]. Antenna array can be classified either as a fixed beam or as an electronic-scanning arrays. In application of satellite communication, fixed beam antennas are useful, whereas in tracking and missile guidance, the use of phased arrays with electronic-scanning capabilities may be necessary. With the help of phased arrays, the main beam can be scanned easily in any direction to form a scanning array. In other words, the radiation from an array can be measured directly by controlling the phase excitation difference between the elements. Planar arrays are more versatile and provide narrow pencil beam and better radiation performance [4-6].

To demonstrate the principle of planar array theory, a 8 × 8 element planar array of CPMA on PTFE Reinforced Quartz at 10GHz is presented here. The array factor of this geometry is obtained with the help of pattern multiplication approach [7]. The far-zone field pattern and other important antenna parameters are computed for two different values of progressive phase excitation difference between the elements and the results are plotted in two principal planes.

The geometry and coordinate system of the array antenna under investigation is shown in Figure 1.

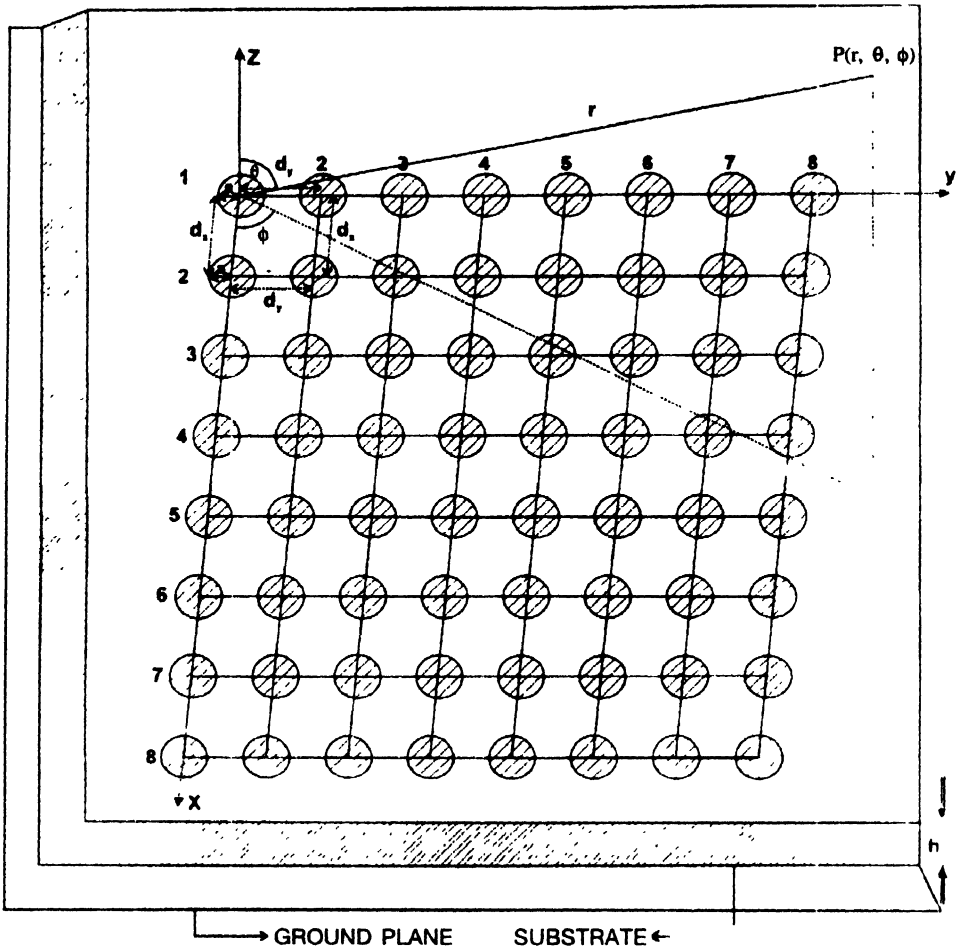


**Figure 1.** Geometry and coordinate system of 8 × 8 element circular patch microstrip planar array.

It consists of 64 identical elements on a dielectric substrate (PTFE Reinforced Quartz) of thickness '$h$' and substrate permittivity $\varepsilon_r = 2.47$. The radius of each element is '$a$'. The array elements which are positioned along $X$-axis are separated by a distance $d_x$ and, those along $Y$-direction are separated by a distance $d_y$. Each patch can be excited by a microstrip transmission line connected to the edge or by a coaxial line from the back at the plane $\phi = 0$. Several investigators [8.9] have considered the patch as a cavity which acts as a disc resonator. In such a geometry $TM_{nm}$ mode with respect to $Z$-axis are excited. The subscripts $n$ and $m$ are the mode numbers associated with $x$ and $y$-directions, respectively.

The total field of the present array antenna can be expressed as

$$E\,(\text{total}) = [\,E\,(\text{single element placed at the origin}) \times \text{array factor (AF)}]. \qquad (1)$$

As the entire array is taken as uniform, the normalized form of the array factor (AF) is obtained and may be written as

$$AF = \frac{1}{64}\,\frac{\sin\left\{4(kd_x \sin\theta\cos\phi + \beta_x)\right\}}{\sin\left\{0.5(kd_x \sin\theta\cos\phi + \beta_x)\right\}} \times \frac{\sin\left\{4(kd_y \sin\theta\sin\phi + \beta_y)\right\}}{\sin\left\{0.5(kd_y \sin\theta\sin\phi + \beta_y)\right\}} \quad (2)$$

Neglecting coupling [10] between the elements, the far-zone field expressions for 8 × 8 element planar array of CPMA are obtained as follows :

$$E_{\theta t} = j^n \frac{Vak_0}{2} e^{-jk_0 r} \cos n\phi \frac{\sin(k_0 h\cos\theta)}{(k_0 h\cos\theta)}$$

$$\left\{J_{n+1}(k_0 a\sin\theta) - J_{n-1}(k_0 a\sin\theta)\right\} \times$$

$$\frac{1}{64}\,\frac{\sin\left\{4(kd_x \sin\theta\cos\phi + \beta_x)\right\}}{\sin\left\{0.5(kd_x \sin\theta\cos\phi + \beta_x)\right\}} \times \frac{\sin\left\{4(kd_y \sin\theta\sin\phi + \beta_y)\right\}}{\sin\left\{0.5(kd_y \sin\theta\sin\phi + \beta_y)\right\}}. \quad (3)$$

Similarly,

$$E_{\phi t} = j^n \frac{Vak_0}{2} \frac{e^{-jk_0 r}}{r} \cos\theta \sin n\phi \frac{\sin(k_0 h\cos\theta)}{(k_0 h\cos\theta)} \times$$

$$\left\{J_{n+1}(k_0 a\sin\theta) + J_{n-1}(k_0 a\sin\theta)\right\} \times$$

$$\frac{1}{64}\,\frac{\sin\left\{4(kd_x \sin\theta\cos\phi + \beta_x)\right\}}{\sin\left\{0.5(kd_x \sin\theta\cos\phi + \beta_x)\right\}} \times \frac{\sin\left\{4(kd_y \sin\theta\sin\phi + \beta_y)\right\}}{\sin\left\{0.5(kd_y \sin\theta\sin\phi + \beta_y)\right\}}. \quad (4)$$

where

| | |
|---|---|
| $a$ | radius of each circular patch, |
| $\beta_x, \beta_y$ | Progressive phase excitation difference along $X$- and $Y$- directions respectively, |
| $E_{\theta t}, E_{\phi t}$ | Components of total electric field vector for EM wave, |
| $h$ | Thickness of dielectric substrate, |
| $J_{n+1}$ | $(n + 1)^{th}$ order Bessel's function of first kind, |
| $J_{n-1}$ | $(n - 1)^{th}$ order Bessel's function of first kind, |
| | Phase propagation constant for EM wave given by $2\pi/\lambda_0$, |
| $V$ | edge voltage at $\phi = 0$, |
| $\lambda_0$ | free space wave length. |

It is pertinent to mention here that the expressions for $E_{\theta t}$ and $E_{\phi t}$ given by eqs. (3) and (4) respectively, involve additional terms containing $\beta_x$, $\beta_y$, $d_x$ an $d_y$. These factors are derived by considering the appropriate geometrical configuration of the array. For the present calculation we need the value of '$a$', the radius of circular patch, which we have determined using the characteristic equation for the resonant frequency ($F_r$) [8] :

$$F_r = \frac{Ck_{..}}{2\pi a\sqrt{\varepsilon_r}}, \tag{5}$$

where $c$ is velocity of light, $k_{nm}$ = 1.84118 ($n$ = 1 and $m$ = 1), integer $n$ corresponds to the order of the Bessel function and the integer $m$ respresents the $m$-$th$ zero of the function ($k_1a$). For any given frequency the mode corresponding to $n = m = 1$ has the minimum radius and is known as the dominant mode.

*Field patterns :*

The total field pattern $R(\theta, \phi)$ is generally obtained from the relation.

$$R(\theta,\phi) = \ _{\theta t} \qquad E_{\phi t} \tag{6}$$

The values of $R(\theta, \phi)$ are computed for a case taking source frequency $F_r$ = 10 GHz, $a$ = 0.56 cm, $\varepsilon_r$ = 2.47, $h$ = 0.16 cm and element separation $d_x = d_y = 0.5\,\lambda_0$ = 1.5 cm for $\phi$ = 0 and $\pi/2$ planes and for two values of progressive phase excitation difference *i.e.* $\beta_x = \beta_y = \pi/2$ and $\pi/3$. The calculated results are plotted in Figure 2, only for $\phi$ = 0 plane because almost similar type of field pattern is observed for $\phi = \pi/2$ plane.

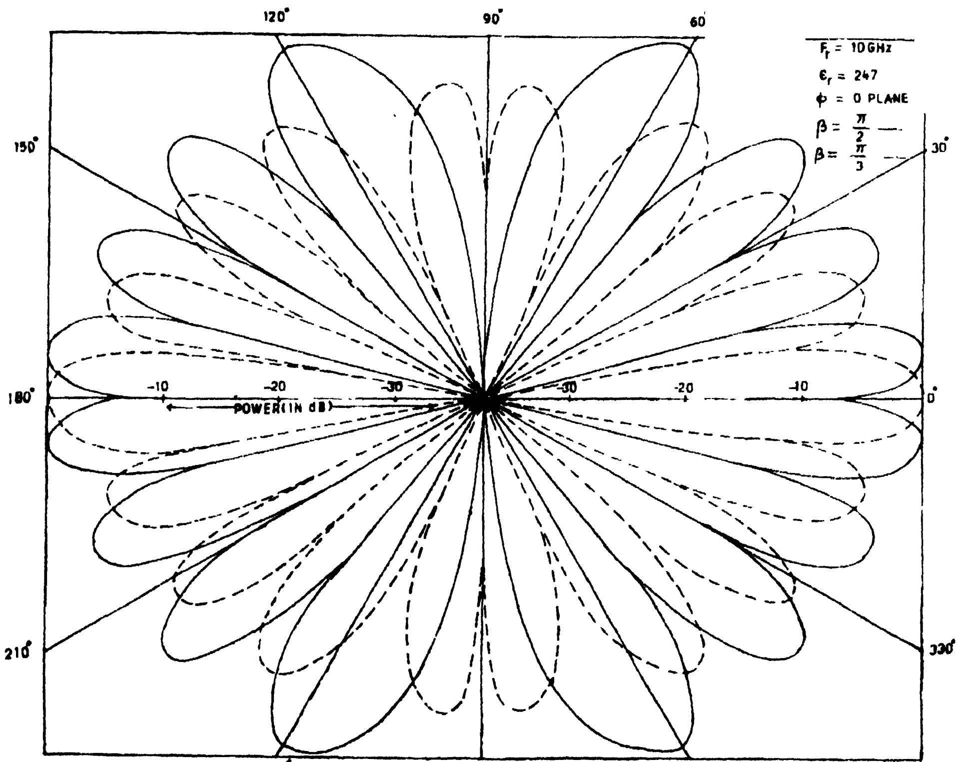


**Figure 2.** Variation of $R(\theta, \phi)$ for 8 × 8 element planar phased array of circular patch microstrip antenna for $\phi$ = 0 plane and $\beta = \pi/2$ & $\pi/3$.

It is observed from the figure that patterns of array antenna are directive in nature and provide simultaneously multibeams of relatively narrow beamwidth. Further, on the variation of progressive phase excitation difference between the elements, the position of main beam and the secondary beams are scanned and the direction of maximum radiation is shifted. We have measured different pattern characteristics of array geometry for both the planes *i.e.* $\phi = 0$ and $\pi/2$ and for $\beta_x = \beta_y = \pi/2$ and $\pi/3$ and are given in Table 1.

**Table 1.** Measured values of pattern characteristics of array geometry.

| Pattern Characteristics | $\phi = 0$ plane | | $\phi = \pi/2$ plane | |
|---|---|---|---|---|
| | $\beta_x = \beta_y = \pi/2$ | $\beta_x = \beta_y = \pi/3$ | $\beta_x = \beta_y = \pi/2$ | $\beta_x = \beta_y = \pi/3$ |
| Half power beam width (major lobe) | 10° | 12° | 10° | 12° |
| Direction of max. radiation (major lobe) | 5° | 0° | 5° | 0° |
| First null beam width | 15° | 20° | 15° | 20° |
| Half power beam width (first minor lobe) | 10° | 11° | 10° | 9° |
| Direction of max. radiation (first minor lobe) | 22° | 15° | 21° | 15° |
| Side lobe level (SLL) (dB) | -1 94 | -3.9 | -2 11 | -4.01 |
| Total shift (major lobe) | 5° | | 5° | |
| Total shift (first minor lobe) | 7° | | 6° | |

*Radiation conductance :*

By integrating the Poynting vector over a large sphere [11], the expressions for radiation conductance of the array geometry may be expressed as

$$G = \frac{2P_r}{V^2}, \tag{7}$$

where

$$P_r = A\int_0^{2\pi}\int_0^{\pi} \frac{\sin^2(k_0 h \cos\theta)}{(k_0 h \cos\theta)^2} \frac{\sin^2\{4(kd_y \sin\theta\sin\phi + \beta_y)\}}{\sin^2\{0.5(kd_y \sin\theta\sin\phi + \beta_y)\}};$$

$$\frac{\sin^2\{4(kd_x \sin\theta\cos\phi + \beta_x)\}}{\sin^2\{0.5(kd_x \sin\theta\cos\phi + \beta_x)\}}\Big\{\cos^2 n\phi\left[J_{n+1}(k_0 a\sin\theta) - J_{n-1}(k_0 a\sin\theta)\right]^2$$

$$+\cos^2\theta\sin^2 n\phi\left[J_{n+1}(k_0 a\sin\theta) + J_{n-1}(k_0 a\sin\theta)\right]^2\Big\} \times \sin\theta\, d\theta\, d\phi, \tag{8a}$$

$$A = \frac{j^{2n} a^2 k_0^2 V^2 e^{-2jkr}}{32768\eta}$$

$$V \text{ (Edge voltage)} = hE_0 J_n (k_0 a),$$
$$\eta \text{ (Free space Impedance)} = 120\,\pi. \tag{8b}$$

*Directive gain :*

The directive gain of an antenna in a given direction is defined as the ratio of the radiation intensity (U) in that direction to the average radiated power ($P_r$) [7]. For the given geometry it is expressed as :

$$D_g = \frac{4\pi U}{P_r}, \text{ for } \theta = \frac{\pi}{5}, \phi = \frac{6\pi}{5} \tag{9}$$

Therefore,

$$D_g = \frac{4\pi M_e}{I}, \tag{10}$$

where $$I = \int_0^{2\pi} \int_0^{\pi} M_e \sin\theta \, d\theta \, d\phi \tag{11}$$

and

$$M_e = \frac{\sin^2 (k_0 h \cos\theta)}{(k_0 h \cos\theta)^2} \times \frac{\sin^2 \{4 (kd_x \sin\theta \sin\phi + \beta_x)\}}{\sin^2 \{0.5 (kd_x \sin\theta \sin\phi + \beta_y)\}}$$

$$\frac{\sin^2 \{4 (kd_x \sin\theta \cos\phi + \beta_x)\}}{\sin^2 \{0.5 (kd_x \sin\theta \cos\phi + \beta_x)\}} \times \left\{\cos^2 n\phi \left[J_{n+1} (k_0 a \sin\theta) - J_{n-1} (k_0 a \sin\theta)\right]^2\right.$$

$$\left. + \cos^2\theta \sin^2 n\phi \left[J_{n+1}(k_0 a \sin\theta) + J_{n-1}(k_0 a \sin\theta)\right]^2\right\}. \tag{12}$$

The radiation intensity (U) has been estimated for $\theta = \pi/5$, $\phi = 6\pi/5$ for two different values of progressive phase excitation difference *i.e.* $\beta_x = \beta_y = \pi/2$ and $\pi/3$ by taking same input parameters. For the calculation of $D_g$, the integral involved in eq. 8(a) has been solved using Numerical method [12]. The calculated values are given in Table 2.

**Table 2.** Calculated values of radiation conductance and directive gain of array geometry.

| Antenna parameters | Phase excitation difference | |
|---|---|---|
| | $\beta_x = \beta_y = \pi/2$ | $\beta_x = \beta_y = \pi/3$ |
| Radiation conductance (G) (mho) | $9 \times 10^{-4}$ | $.797 \times 10^{-4}$ |
| Directive gain (Dg) (dB) | 17.26 | 25.0 |

It is observed from the table that there is a significant change in the values of radiation conductance and directive gain on variation of progressive phase excitation difference between the elements of the array geometry. It is interesting to note that the array provides a considerably higher gain (25.0 dB) at $\beta_x = \beta_y = \pi/3$

In this paper, a 8 × 8 element planar array of CPMA has been investigated with emphasis on scanning phenomenon. It is observed that there is a significant change in the radiation characteristics of the array geometry due to the increase of number of elements and the variation of progressive phase excitation difference and it provides a multibeam pattern of relatively narrow beam width. The computation has been made for two values of phase shift *i.e.* $\beta_x = \beta_y = \pi/2$ and $\pi/3$ for $\phi = 0$ and $\pi/2$ planes but the field patterns are shown only for $\phi = 0$ plane in Figure 2. A comparison of pattern characteristics of the array geometry is given in Table 1. It can be seen from the Table 1 that the position of the main beam is shifted by $5^0$ in both the planes. A narrow beam with a HPBW of $10^0$ is obtained at $\beta_x = \beta_y = \pi/2$. There are number of secondary lobes having narrow pencil like shape obtained for both the planes. It is also interesting to note that this scanning effect provides low value of SLL about 4 dB down. The calculated values of radiation conductance and directive gain of the given geometry are shown in Table 2. It has been seen from Table 2, that the given array antenna has better radiation conductance and higher directive gain in the desired direction, *i.e.* for $\theta = \pi/5$ and $\phi = 6\pi/5$. It can be concluded from the results that at $\beta_x = \beta_y = \pi/3$, the array geometry provides a better radiation performance. A possible use of the present array geometry may be in search / track applications in radar system due to its unique scanning capabilities with high directive gain.

**Acknowledgment**

The authors are grateful to Prof. Jai Shanker, Head, Department of Physics, Dr. B. R. Ambedkar University, Agra for providing necessary facilities and constant encouragement.

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